AMENDMENTS TO THE SPECIFICATION

Please replace the **ABSTRACT** with the following paragraph:

ABSTRACT

Techniques are described for maintaining the orthogonality of waveforms transmitted in ultra wideband (UWB) multi-user wireless communication systems. The multi-stage block-spreading (MS-BS) techniques described herein deterministically eliminate multiple user interference (MUI) in the presence of frequency-selective fading channels. A transmitter includes a block-spreading unit to generate a stream of frames from a block of information bearing symbols by applying an orthogonal set of spreading codes, such as direct sequence code-division multiple access (CDMA) codes or digital carrier frequency multiple access codes, such that the frames corresponding to different blocks of the symbols are interleaved. The transmitter further includes a time-hopping spreading unit to generate a stream of chips from the stream of frames by applying an orthogonal set of time-hopping (TH) spreading codes such that chips corresponding to different frames are interleaved. ~~The stream of chips may be padded with a number of guard chips determined as a function of the length of the communication channel.~~

Please replace paragraph **[0032]** with the following paragraph:

[0032] The application of a time-hopping (TH) spreading code to the information bearing symbols produces a set of "chips" over which each symbol 1A, 1B is transmitted. Each frame ~~12~~ 2 comprises N_c, e.g. $N_c = 3$, chips with each chip 8 having chip duration T_c 9. Frame duration T_f is then equivalent to $N_cT_c + T_g$, where T_g is a guard time to account for processing delay at the receiver between two successively received frames. For simplicity T_g is set to zero for all following equations. A nonzero value for T_g does not impose any limiting consequences. The u^{th} user's transmitted waveform $v_u(t)$ ~~18~~ is given in accordance with equation (1):

$$v_u(t) = \mathrm{P}_u \sum_{-\infty}^{+\infty} w(t - kT_f - c(k)T_c - \tau_{J_u}(\lfloor k / N_f \rfloor)) \quad (1)$$

where P_u is the u^{th} user's transmission power, w(t) denotes the ultra-short pulse 7 and $\dot{c}_u(k) \in [0, N_c - 1]$ ~~11~~ 3 is a periodic pseudo random sequence with period $P_{\dot{c}}$ equal to N_f. Ultra-short pulse 7 typically has a duration between 0.20 and 2.0 nanoseconds and may be selected as a Gaussian monocycle, a Gaussian biphase monocycle, a doublet consisting of a positive Gaussian pulse followed by its negative, and the like. The role of $\dot{c}_u(k)$ 3 is to enable both multiple users over a communication channel and security.

Please replace paragraph **[0033]** with the following paragraph:

[0033] Each signaling interval T_s 6 of the transmitted waveform ~~18~~ in equation (1) includes N_f copies of a single symbol 1A, 1B, i.e. one per frame 2, with pulse 7 time-shifted in each frame 2 according to the symbol value, e.g. it is shifted by τ_m for $I_u(\lfloor k/N_f \rfloor) = m$ where $m \in [0, 1, \ldots, M-1]$. In order to ensure orthogonal modulation, PPM modulation delays τ_m must satisfy $\tau_m - \tau_{m-1} \geq T_w$ for $\forall\, m \in [1, 2, \ldots, M-1]$. Thus, chip duration T_c 9 should be chosen to satisfy $T_c \geq \tau_{m-1} + T_w \geq MT_w$.

Please replace paragraph **[0035]** with the following paragraph:

[0035] Because ~~c(k) 3~~ $\dot{c}_u(k) \in [0, N_c-1]$ 3 is an integer, $w_m(t)$ is shifted by an integer multiple of T_c 9. As a result waveform $v_{u,m}(t)$ can be written in equation (5) accordingly. Equation (5) can be viewed as a linearly modulated waveform with symbol rate $R_s = 1/T_c$ while equation (2) can be viewed as the superposition of M linear modulators, each with a different pulse function $w_m(t)$.

$$v_{u,m}(t) = \mathrm{P}_u \sum_{k=-\infty}^{k=+\infty} v_{u,m}(n) w_m(t - nT_c) \quad (5)$$

Sequence $v_{u,m}(n)$ is dependent on $s_{u,m}(k)$ and ~~c(k)~~ $\dot{c}_u(k)$ 3. Chip-rate code sequence $c_u(n)$ 5 with period $P_c = N_c P_{\dot{c}}$ is defined via ~~c(k) 11~~ $\dot{c}_u(k)$ 3 as given in equation (6).

$$c_u(n) := \delta(\lfloor n / N_c \rfloor N_c + \dot{c}_u(\lfloor n / N_c \rfloor) - n) \quad (6)$$

The relation between $\dot{c}_u(k)$ 3 and $c_u(n)$ 5 is given by the mapping between chip index n and frame index k. As a result, the u^{th} user's chip sequence on the m^{th} branch $v_{u,m}(n)$ can be expressed according to equation (7).

$$v_{u,m}(n) = s_{u,m}(\lfloor n / N_c N_f \rfloor) c_u(n) \quad (7)$$

Please replace paragraph **[0037]** with the following paragraph:

[0037] Although T_g was set equal to zero, the model can also include T_g as nonzero. This can be accomplished by setting $T_g = N_g T_c$ with N_g being an integer and restricting $\dot{c}(k)$ 3 to take on values $[0, N_c'-1]$, where $N_c' := N_c - N_g$. Hereafter, all equations and derivations will assume $T_g=0$.

Please replace paragraph **[0045]** with the following paragraph:

[0045] FIG. 3 is a block diagram illustrating in further detail multi-user communication system 10 of FIG. 2 using multi-stage block-spreading (MS-BS). For simplicity, the m^{th} branch of a transmitter 12 and the $m^{\prime\,th}$ branch at a receiver 14 are given in detail for the u^{th} user. Transmitter 12 applies MS-BS techniques and pulse shaping to chip-rate information bearing symbols s_u~~(m,n) 12~~ $s_{u,m}(n)$ 20 and transmits the MS-BS M-ary pulse position modulated (PPM) IRMA waveform $v_{u,m}(t)$ 28. Receiver 14 receives chip-rate sampled sequence $x_{m'}(n)$ 38 and outputs symbol estimates 49.

Please replace paragraph **[0047]** with the following paragraph:

[0047] Serial to parallel (S/P) converter ~~20~~ 21 of transmitter 12 parses serial chip-rate data stream $s_{u,m}(n)$ 20 into blocks of K symbols 22, each symbol representing a discrete information bearing value, as defined in equation (8).

$$s_{u,m}(i) := [s_{u,m}(iK), \ldots, s_{u,m}(iK+K-1)]^T \quad (8)$$

Please replace paragraph **[0050]** with the following paragraph:

[0050] Similarly, TH spreading unit 25 applies a TH spreading code selected from a set of mutually orthogonal TH spreading codes according to the address assigned to the u^{th} user. Each block of Q frame-rate signals of data stream ~~43~~ 24 is spread into a stream of P chips wherein the chips corresponding to different frames are interleaved. In other words, TH block-spreading unit 25 spreads a block of Q frame-rate signals into P chip-rate signals followed by chip interleaving and zero padding via spreading matrix $\mathbf{C}_{uA}$ according to equation (12).

$$\mathbf{v}_{u,m}(i) = \mathbf{C}_{uA}\, \check{\mathbf{s}}_{u,m}(i) \quad (12)$$

TH spreading matrix $\mathbf{C}_{uA}$ is derived from equations (13, 14) and defined in equation (15).

$$\mathbf{c}_{uA}^{(q)} := [c_{uA}(qN_c), c_{uA}(qN_c+1), \ldots, c_{uA}(qN_c+N_c-1)]^T, \text{ for } q \in [0, N_f-1] \quad (13)$$

Recall that c_{uA} is given by equation (6). Matrix $\mathbf{C}_{uA}^{(q)}$ is defined in equation (14).

$$\mathbf{C}_{uA}^{(q)} := \mathbf{c}_{uA}^{(q)} \otimes \mathbf{T}_{zp}, \text{ where } \mathbf{T}_{zp} := [\mathbf{I}_K, \mathbf{0}_{K \times L}]^T \text{ for } \quad (14)$$

Zero-padding matrix $\mathbf{T}_{zp}$ is a (K + L) x K matrix and appends L zeros at the end of each column upon multiplication. The guard chips may be null values as implemented here with zero padding via matrix multiplication. TH spreading matrix $\mathbf{C}_{uA}$ can then be written as in equation (16).

$$\mathbf{C}_{uA} := \text{diag}\{\, \mathbf{C}_{uA}^{(0)}, \mathbf{C}_{uA}^{(1)}, \ldots, \mathbf{C}_{uA}^{(N_f-1)} \} \quad (15)$$

TH spreading matrix $\mathbf{C}_{uA}$ is of size P x Q, where $P = N_f N_c(K + L)$. The parameter L is determined by the effective length of channel 16 in discrete time and is calculated below. As a result, data stream 26 at the output of TH block-spreading unit 25 is given by the P x 1 vector on the m^{th} branch in equation (16) and is given in matrix-vector form according to equation (17).

$$\mathbf{v}_{u,m}(i) := [v_{u,m}(iP), \ldots, v_{u,m}(iP+P-1)]^T \quad (16)$$

$$\mathbf{v}_{u,m}(i) = \mathbf{C}_{uA}\, \mathbf{D}_{uB}\, \mathbf{s}_{u,m}(i) \quad (17)$$

Please replace paragraph **[0053]** with the following paragraph:

[0053] The chip-sampled discrete time equivalent finite impulse response (FIR) channel can be represented according to equation (21) where * denotes convolution.

$$h_{u,m',m}(l) := (w_m * g_u * \bar{w}_{m'})(t)|_{t=lT_c} \quad (21)$$

Equivalent FIR channel of equation (21) of order L_u includes the u^{th} user's asynchronism in the form of delay factors as well as transmit-receive filters, and the multi-path effects. AWGN 34, denoted $\eta(t)$, is effectively sampled at chip-rate, $t = nT_c$, and can be represented as sampled AWGN noise according to equation (22).

$$\eta_{m'}(n) := (\eta * \bar{w}_{m'})(t)|_{t=nT_c} \quad (22)$$

Receiver 14 receives the chip-sampled matched filter output ~~28~~ 38 from matched filter 36 as given in equation (23).

$$x_{m'(n)} = \sum_{u=0}^{N_u-1}\sum_{m=0}^{M-1}\sum_{l=0}^{L} P_u h_{u,m',m}(l) v_{u,m}(n-l) + \eta_{m'}(n) \quad (23)$$

N_u is the number of users, L is the maximum length of communication channel 16 in discrete time for the u^{th} user, and M is the number of PPM pulse shapers.

Please replace paragraph **[0066]** with the following paragraph:

[0066] If the number of N_u users satisfies $N_u \leq N_c N_f$, then a given TH address is assigned to a group of $\lfloor N_u/N_c \rfloor$ or $\lceil N_u/N_c \rceil$ users. An additional set of MU addresses are assigned to be able to resolve users in the same group by employing a unique mapping to each of the $\lfloor N_u/N_c \rfloor$ or

$\lceil N_u/N_c \rceil$ users in the same group. As a result, the same MU address can be assigned to several users that belong to different groups since groups are differentiated via their TH address. For example, the u^{th} user may be assigned TH address and MU address with index given by its $\{u_A, u_B\}$ pair according to equations (61, 62) respectively.

$$u_A = u \pmod{N_c} \quad (61)$$
$$u_B = \underline{\lfloor u / N_c \rfloor,\ u \in [0, N_cN_f\text{-}1]}\ \cancel{u \pmod{N_f}} \quad (62)$$

Please replace paragraph **[0067]** with the following paragraph:

[0067] FIG. 5 is a block diagram that illustrates an example <u>transmission of a</u> M-ary PPM-IRMA signal of the u^{th} user's information bearing symbols during the n^{th} chip duration <u>in an IRMA system 60</u>. The u^{th} user's transmitted symbol during the n^{th} chip duration is $I_u(\lfloor n/N_cN_f \rfloor)$ 61. The orthogonal M-ary PPM of the u^{th} user in FIG. 1 can be viewed as having M parallel branches 62 with each parallel branch realizing a shifted version of the pulse stream. However, one branch out of the M parallel branches can be sufficiently selected depending on the symbol value.

Please replace paragraph **[0075]** with the following paragraph:

[0075] FIG 10 illustrates BER performance of the conventional IRMA system with one, two, three, and four users compared to an MS-BS IRMA system with the active number of users in the range of $1 \leq N_u \leq 32$ in an uplink scenario with perfect power control, i.e. P_u for all users. In particular, FIG ~~9~~ <u>10</u> illustrates how the BER performance of a conventional IRMA system degrades as the number of users increases while the BER performance of the MS-BS IRMA system remains invariant as the number of active users changes in the specified range.

Please replace paragraph **[0076]** with the following paragraph:

[0076] FIG 11 illustrates BER performance of the conventional IRMA system compared to an MS-BS IRMA system in an uplink scenario with two active users, user 1 being the desired user, and the effective transmission power of user 2 twice that of user 1. In particular, FIG ~~10~~ <u>11</u>

illustrates that the imperfect power control has no effect on the BER performance of the MS-BS IRMA system while the conventional IRMA system encounters degradation in BER performance.